Project ANR-13-JCLI-00001-01

FuturAgua

Belmont Forum-GS Heads of Research Councils Program 2013

A IDENTIFICATION

Project acronym	FuturAgua
Project title	Enhancing adaptation and resilience to drought in dry tropical socio-ecological systems: The Guanacaste, Costa Rica example
Coordinator of the French part of the project	Gregoire Leclerc (CIRAD)
Coordinator of the Canada part of the project	Douw Steyn (UBC)
Coordinator of the US part of the project	Mitch Small (CMU)
Project coordinator	Tim McDaniels (UBC)
Project period Start date End date	 1/9/2013 (UBC, CMU) - 1/12/2013 (CIRAD) 30/11/2017
Project website, if applicable	http://futuragua.ca

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Date of writing	20/2/2018

List of partners involved at the end of the project (company/organization and principal investigator)	Centre de Coopération Internationale en Recherche Agronomique pour le Développement (Grégoire Leclerc); University of British Columbia (Douw Steyn, NSERC funding); Carnegie Mellon University (Micth Small, NSF funding); Centro Agronómico Tropical de Investigación y Enseñanza (Raffaele Vignola, ANR funding through CIRAD subcontracting).

B CONSOLIDATED PUBLIC SUMMARY

B.1 INSTRUCTIONS FOR CONSOLIDATED PUBLIC SUMMARIES

B.2 CONSOLIDATED PUBLIC SUMMARY IN FRENCH

Titre : ***Adaptation au changement climatique pour la sécurité hydrique dans le Guanacaste, Costa Rica.***

Objectif: ***Améliorer la résilience à la sécheresse dans le nord-ouest du Costa Rica dans un contexte de gouvernance faible, de manque d'informations pratiques et de changement climatique.***

FuturAgua avait pour objectif d'aider à formuler et à éclairer les choix en matière d'adaptation pour la sécurité de l'eau dans les systèmes socio-écologiques (SES) sujets à la sécheresse. Les institutions de recherche, avec l'appui des gouvernements locaux et des ONG ont tenté de contribuer à renforcer la résilience à la sécheresse dans la région du Guanacaste au Costa Rica. Le projet de recherche a été conçu pour répondre à deux grands objectifs: (i) contribuer aux efforts scientifiques mondiaux pour l'adaptation au changement climatique, et (ii) aider à soutenir les efforts de la société civile et des agences de l'Etat pour améliorer la résilience à la sécheresse et aux pénuries d'eau du Guanacaste. Ce projet était guidé par la conviction que l'amélioration de la sécurité de l'eau douce nécessite des avancées conceptuelles et des nouvelles méthodes d'analyse, de nouvelles connaissances scientifiques et une meilleure compréhension des réactions humaines et institutionnelles aux informations incertaines (p. ex. prévisions de sécheresse). Ces progrès servent de base (i) à une meilleure compréhension de la résilience à la sécheresse dans les SES, (ii) à l'amélioration de la valeur des informations incertaines et (iii) à l'incitation de réponses sociétales résilientes à la sécheresse, dans le cadre de systèmes de gouvernance multi-échelle.

Méthodologies: ***Recherche interdisciplinaire à l'interface science-société.***

Notre équipe de spécialistes en sciences naturelles et sociales a mobilisé des liens bien établis avec des organisations de la société civile et des organismes de gestion de l'eau dans la région. Les coordonnateurs scientifiques du projet ont élaboré le plan de recherche en consultation avec les intervenants dans le but collectif de contribuer à la gestion durable des ressources en eau pour le bien-être des membres de la communauté et des écosystèmes dans les années à venir. 50 chercheurs (26 du consortium), 4 doctorants, 2 étudiants de maîtrise et 11 assistants ont mené des recherches analytiques et de terrain pour étudier divers aspects des dimensions environnementales et sociales de la gestion de l'eau et de la résilience à la sécheresse dans la région. Avec l'appui d'un coordonnateur de projet sur place, les chercheurs ont maintenu une étroite collaboration avec les membres du comité consultatif du projet, ce qui a aidé à mieux orienter le projet et à améliorer sa portée locale. Les méthodes comprenaient l'installation de tours de covariance Eddy dans les fermes, des capteurs à faible coût dans les rivières et les puits,

de la modélisation (multi-agents, statistique, économique et hydrologique), des approches participatives par scénarios et des entrevues sur le terrain.

Principaux résultats et impacts

Nous avons quantifié les eaux « bleues » et « vertes » pour trois grandes cultures de la région et avons élaboré des modèles hydrologiques et des indicateurs pour éclairer les scénarios climatiques et d'utilisation de l'eau. Nous avons évalué les perceptions à l'égard des changements et des prévisions climatiques, ainsi que les mesures incitatives dans les secteurs de l'agriculture et du tourisme. Le processus a permis d'établir des bases solides pour la résilience dans la région: le partage des connaissances fondées sur des évidences, l'établissement de relations de confiance et de partenariats, ainsi que des jeux pour l'éducation environnementale et des outils d'évaluation d'alternatives sociales et techniques, ce qui a permis d'améliorer la prise de décisions et la gestion adaptative dans un contexte d'incertitude et de points de vue multiples.

Production scientifique et brevets

Futuragua a produit 10 articles à comité de lecture (plusieurs autres seront soumis en 2018), 9 notes de recherche en espagnol, ainsi que 3 thèses de doctorat (une autre en cours) et 2 mémoires de maîtrise. 3 nouveaux projets ont été obtenus, et un symposium scientifique a été organisé à Nicoya. Deux outils et la nouvelle version de la plateforme de modélisation open source Cormas sont disponibles gratuitement. Les capteurs Arduino sont maintenant la propriété d'UNA et de NicoyAgua.

Informations factuelles

Futuragua est un projet de recherche en collaboration pour le Forum Belmont 2012 sur la sécurité de l'eau douce. Il s'est déroulé au Costa Rica entre 2013 et 2017 et a impliqué des équipes de l'Université de Colombie-Britannique (Canada), de l'Université Carnegie Mellon (USA) et du Cirad (France), financées par leurs conseils de recherche respectifs: CRSNG (448k€), NSF (484k€) et ANR (449k€).

B.3 CONSOLIDATED PUBLIC SUMMARY IN ENGLISH

***Title:** Adaptation to climate change for freshwater security in Guanacaste, Costa Rica.*

***Objective:** Enhancing resilience to drought in northwestern Costa Rica in a context of weak governance, lack of actionable information, and climate change.*

FuturAgua aimed at helping shape and inform future adaptation choices for water security in drought-prone social-ecological systems (SES). Research institutions, local governments and NGOs were drawn together to conduct research activities to enhance resilience to drought in the

Guanacaste region of Costa Rica. The research project was designed to address two broad objectives: (i) to contribute to global science efforts to understand climate change adaptation, and (ii) to help support civil society and agency efforts to make Guanacaste more resilient to potential drought and water shortages in the future. This project was guided by the belief that improving freshwater security requires advances in conceptual knowledge and analytical methods, new scientific insights, and improved understanding of human and institutional responses to uncertain information (e.g. drought forecasts). These advances provided the basis for (i) better understanding of resilience to drought in dynamic SES, (ii) enhancing the value of uncertain information, and (iii) spurring resilient societal responses to drought, within multi-scale governance systems.

***Methodologies:** Evidence and process based interdisciplinary research at the science-society interface.*

Our team of natural and social scientists worked through well-established regional linkages to civil society organizations and water management agencies in seasonally-arid Guanacaste. The project PIs developed the research plan in consultation with the stakeholders with the collective goal of contributing to the sustainable management of water resources in the region for the wellbeing of community members and ecosystems in the years to come. 50 researchers (26 from the consortium), 4 PhD students, 2 M. Sc. students and 11 assistants, conducted analytic and field research to investigate various aspects of the environmental and social dimensions of water management and drought resilience in the region. With the support of a project coordinator based on-site, the researchers maintained a close collaboration with members of the project advisory committee that helped steer the project and improve its local reach. Methods included Eddy Covariance towers in farms, low cost sensors in rivers and wells, modelling (agent-based, statistical, economic and hydrologic), participatory scenario approaches, and field interviews.

Main results and impact

We quantified blue and green water for 3 major crops and developed hydrologic models and indicators for climate and water use scenarios. We assessed perceptions about climate change and forecasts, as well as incentives in the agriculture and tourism sectors. The process established strong bases for resilience in the region: evidence-based knowledge sharing, trust building and partnerships, as well as games for environmental education and tools for evaluation of social and technical alternatives, which lead to improved decision-making and adaptive management in a context of uncertainty and multiple viewpoints.

Scientific production and patents

Futuragua produced 10 peer-reviewed papers (several more are being submitted in 2018), 9 research briefs in Spanish, as well as 3 PhD theses (one more on-going) and 2 M. Sc. thesis. 3 new projects have been awarded, and a scientific symposium has been organized in Nicoya. Two tools

and the new version of open source modelling platform Cormas are freely available. The Arduino sensors are now property of UNA and Nicoyagua.

Futuragua reseachers and key local actors at the project closing event in Nicoya, Costa Rica, November 4, 2017.

Factual information

Futuragua is a collaborative research project for the 2012 Belmont Forum Freshwater security call. It unfold in Costa Rica during 2013-2017 and involved teams from the University of British Columbia (Canada), Carnegie Mellon University (USA), and CIRAD (France), which were funded by their respective research councils NSERC (448k€), NSF (484k€), and ANR (449k€).

C SCIENTIFIC REPORT

Confidential scientific report: **NO**

C.1 REPORT SUMMARY

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C.2 CHALLENGES AND ISSUES, STATE OF THE ART

International assessments have called for increased attention to how and where climate change will create increased risk of insufficient freshwater supplies for current and future users in arid and semi-arid regions (Kundewitz et al., 2007; Vörösmarty et al., 2010, Belmont Forum 2012). The underlying intent of these calls is to foster research to build greater drought resilience in socio-ecological systems, thus making it possible for nature and humans as part of it to better cope with a changing climate in freshwater-limited regions (Walker, et al, 2004). A key focus of these calls is the need for integrated regionally-oriented case studies that link natural and social science researchers with civil society and agencies (Delgado-Serrano et al, 2017), in order to build useable knowledge that directly addresses issues of importance to regional stakeholders in minimizing the effects of drought. An important rationale for this focus is recognition of the interconnections among multiple levels of governance in addressing water management and drought, meaning that attention to multiple scales of governance is crucial (Reynolds, et al, 2007; McDaniels, Dowlatabadi and Stevens, 2005).

Research designs for large-scale case studies that are focused on building resilience for water security are not commonplace. To avoid a strictly descriptive approach, there is strong need to tie research activities to the interests and capacities of civil society groups, and to focus on methods that support decision-aiding efforts, while building capacity. To avoid a strictly social-discourse approach, there is a clear need for sound biophysical science efforts and advances in methods and applications that link a changing climate to changing hydrology, water demands and water availability. Overall, studies should contribute to scientific understanding as well as, through co-design, institutional and individual efforts to build drought resilience through adaptation efforts. The findings should be generalizable, so they contribute to insight on larger scales than the immediate study region (Leclerc and Hall, 2013).

FuturAgua is an attempt to address the freshwater security challenge in a drought-prone region of Costa Rica. Media reports supplemented with observations of the research team indicate that Costa Rica, Nicaragua, and Colombia, among other Latin countries, have been suffering unusually prolonged seasonal droughts, which triggers water-related conflicts (Kuzdas et al, 2012), and a change in the onset of early rains that affects smallholder agriculture. Water stress is not only dependent on climatic conditions; the upward shift in societal demand has also a big role in it. These factors make our project even more relevant since it involves measurements of ongoing changes in climate and also stakeholders' engagement. Conflicts over water use have intensified among many users in this region, among different communities, different sectors, and

different ecosystem services. Yet scientific understanding is limited for the social and environmental systems dependent on scarce and contested water resources. Knowledge of hydrological and ecological systems is often scant, and interventions for action are not apparent (Grafton et al. 2012).

The overall objective of FuturAgua is to identify future adaptation choices regarding drought, with an emphasis on building resilience to water scarcity in drought-prone SES. We seek to build science and influence choices relevant in the project region; we intend to make the science and decision-related insights relevant for other tropical areas in which drought is a threat and SES are similar in terms of water shortage. In short, FuturAgua aims at providing the basis for (i) better understanding of resilience to drought in dynamic SES (ii) enhancing the value of uncertain information, and (iii) spurring resilient societal responses to drought, within multi-scale governance systems.

C.3 SCIENTIFIC AND TECHNICAL APPROACH

Freshwater security requires advances in conceptual knowledge and analytical methods, new scientific insights, and improved understanding of human and institutional responses to uncertain information (e.g. drought forecasts). This relates to the concept of value of information that cannot be obtained without paying attention to the interests, concerns and values of potentially affected parties. In a project intended to foster drought resilience in SES, involvement of affected parties, as well as governance entities with responsibility for translating science into effective action are both crucial for success (Stern and Fineberg, 2006). Hence, unfolding the research with (i) guidance from affected parties about their overall concerns and priorities; (ii) an acknowledgement of uncertainty at many levels (iii) involving existing and emerging governance entities in transformative scenario planning and decision-making.

Our integrated team of natural and social scientists, working with well-established regional linkages to civil society organizations and water management agencies, pursues these needs through a collaborative regional study in seasonally-arid Guanacaste and Nicoya regions of Costa Rica. Nearly all project researchers and seven representatives from NGOs and agencies met at a project planning meeting to further develop the proposal and ensure its relevance for both research and civil society interests. The project Stakeholder Advisory group (SAG) was formed to help steer the project and improve its reach, through three annual meetings which were attended by nearly all researchers, as well as individual meetings as needed.

Collaboration between research organizations during the project was a priority. A consortium agreement was jointly developed at the start of the project to establish guidelines for FuturAgua research organizations. Project-wise virtual meetings were held on a bi-monthly basis, where research plans and results were shared. CIRAD/CATIE staff helped UBC and CMU introduce local actors, install equipment, obtain data, revise protocols and perform interviews. Researchers from all 4 FuturAgua institutions met in several occasions during the course of the project: at

AGU and Belmont meetings in 2014 and 2016, in Costa Rica once a year, in UBC in 2016 and 2017. This allowed to better orient each organization's research and ensure a coherent interaction with local organizations, however we did not achieve the level of transdisciplinarity that we initially sought. This was due to geographical and time constraints, but also to the nature of Ph.D. work which is highly individual and bounded by faculty and copyright requirements.

The research partners had different roles and modus operandi in the consortium. NSERC and NSF funded UBC and CMU PhD students who performed most of the research under supervision of their faculty staff. The UBC team focused on biophysical research and on valuation of ecosystem services; they also obtained some funding to complement CIRAD's dissemination efforts. CMU targeted climate scenarios and mental models. CIRAD and CATIE took the lead on agriculture and on stakeholder's engagement and participatory modelling. CIRAD and CATIE staff were based in Costa Rica, with a project assistant on-site, and were directly involved in the research activities, with support from M.Sc. students and consultants and a strong presence in the field, which allowed to develop highly participatory action-research, as well as in local communication and dissemination activities.

From 2013 to 2017, 50 researchers (26 from the consortium), 4 PhD students, 4 M. Sc. students and 9 assistants, conducted analytic and field research to investigate various aspects of the environmental and social dimensions of water management and drought resilience in the region. Methods included Eddy Covariance towers in farms, low cost sensors in rivers and wells, modelling (agent-based, statistical, economic and hydrologic), participatory scenario approaches, and field interviews.

FuturAgua focuses on filling knowledge gaps on 3 fronts:

Past, present and future climate and the water budget: There is a need for assessing climate change and forecasts in the region (Aguilar et al, 2005)), focusing on key indicators needed for agriculture and freshwater security (Sultan et al, 2011). Moreover, there is a lack of local data on water footprints and water budget, especially concerning aquifers and agriculture (Falkenmark & Rockström, 2006). Those knowledge gaps undermine effective water management in the region.

Perceptions, ecosystem services and adaptation: There is no information regarding flows needed for ecological uses, nor the ecosystem services (ES) provided to society from resources dependent on those flows in the Guanacaste region (Brauman et al, 2007). Little or no understanding exists of how water-related institutions do, could or should use drought forecasts (Ziervogel et al, 2005). Stakeholders in the region anticipate great vulnerability to scarcity and worsening water conflicts if the aquifer is depleted or recharge is slowed (La Nacion, 2015).

Governance, co-design and stakeholders' engagement: Water conflicts have been always related to lack of communication, trust, or knowledge sharing among stakeholders. Also, processes are often very top-down, under a legal umbrella that fails to be enforced and in which free riders

undermine water security in the region (Dietz et al, 2003). There is a need to improve the way scientific information is generated and used, stimulate co-design and learning, and accompany current planning, decision making and advocacy (De Bruin & Bostrom, 2013; Bommel et al, 2014).

C.4 ACHIEVED RESULTS

Past, present and future climate and the water budget (UBC, CMU, CIRAD)

We analyzed rainfall variability in Guanacaste, and found that the annual rainfall cycle can be effectively and simply modelled by a double Gaussian function using monthly totals of rainfall for 38 years of data. The Bayesian analysis does show strong evidence for a negative and highly significant annual Ocean Niño Index (ONI) effect on rainfall. Given the differences among climate model precipitation projections, we then developed a statistical approach to better characterize seasonal patterns of precipitation and to assess the potential impact of climate change on these patterns. A Gaussian mixture model is employed to describe the bimodal pattern of Guanacaste and quantify changes in the seasonal precipitation cycle projected by "Coupled General Circulation Models (CGCMs)". The climate projections are found to be uncertain in both sign and magnitude, especially for the early and late portions of the wet season. Finally, we developed scenarios of future precipitation changes in Northwest Costa Rica based on climate model results and a systematic expert elicitation to assess uncertainties projections of changes in the region's seasonal precipitation pattern. We found considerable uncertainties on whether the mid-summer drought will intensify in a warming world or whether the rainfall season in Northwest Costa Rica will become overall wetter – including during the mid-summer drought – similar to what is expected for tropical regions adjacent to Northwest Costa Rica. However rainfall during the early part of the season may be delayed and weaker in a warmer world.

We also quantified the water footprint and other indicators of water use and water extraction for irrigation of three major crops in Guanacaste, based on measurements from two monitoring stations installed in farms under different climate regimes (sugarcane in a 1100mmm/year rainfall region, Melon/Rice in a 1500mm/year rainfall area). Mean daily water consumption of the three crops was 2.4 l m^{-2} day^{-1}, 3.3 l m^{-2} day^{-1} and 3.5 l m^{-2} day^{-1} for melon, rice and sugar cane respectively. Mainly because of the large differences in the length of growing season of each crop, melon production had the lowest total volume of water consumed for its production or water footprint (177 l m^{-2}), followed by rice (385 l m^{-2}) and sugar cane (1291 l m^{-2}). In annual water budget terms, the crop rotation system of melon/upland rice showed that rainfall exceeded water extraction, leaving a surplus available for groundwater recharge and runoff to surrounding rivers. The annual water budget of sugar cane monoculture showed very low water surplus in 2016 (average annual rain conditions), while in the very dry year of 2015 irrigation was indispensable to cover the minimum water needs of the crop.

We explored the impacts of the combined drivers of climate and water demand on water resources. We focused on the Potrero-Caimital watersheds close to Nicoya and monitored streamflow there for 2.5 years with low-cost open source sensors. We combined this data with groundwater and water use data, and from this, developed a hydrologic model with which we explored climate and water use scenarios. Our results demonstrate that El Niño and La Niña events have a significant impact on available water resources, and further show that effective water management during El Niño years becomes even more a priority with a growing population and growing water demands. We developed a groundwater recharge indicator to help with water-related decision making in advance of dry seasons for years with less than normal water supplies, highlighting the importance of a watershed-based approach for effective water management. The results were presented in a Structured Decision Making workshop where several alternatives for dry areas resilience were discussed as a basis for future planning in the region. The information was presented in 4 matrices at a municipal and household levels, with two kinds of alternatives: policy-based (soft) and infrastructure based (hard) and two contexts: alternatives for managing demand and alternatives for enhancing supply.

Perceptions, ecosystem services and adaptation (UBC, CMU, CIRAD)

A survey with a diverse set of actors of the Guanacaste Region showed that while most share the perception that El Niño and climate change are important drivers of the water system and that additional environmental awareness is needed, they differ in the level of detailed understanding of the water system, in the use of formal forecasts, and in the use of longer-term water management strategies. Large farmers, government agencies, and hydroelectric system managers share similar perceptions to each other while other groups such as small farmers and ASADAs had more diverse opinions including a mistrust of formal forecasts due to their coarse spatial resolution. Our results will help design future forecast communications and in pointing out areas where additional connection and translation work between groups would be beneficial.

We then focused on 61 small farmers in two distant watersheds to build a typology of their agricultural system, learn about their perception of drought and possible adaptations to it, and their perception of the usefulness of climatic forecasts. These results, together with other available information, provided the inputs for a bio-economic model that was used to value several components of adaptation, i.e. irrigation, climatic forecasts, and harvest insurance. Simulations of a typical farm of the region were carried out with different combinations of instruments: irrigation, harvest insurance for rice, a bank loan, and irrigation plus insurance; all with equal probability across 5 climatic situations (from extremely dry to extremely wet). We found that to be useful for such a farm, forecasts of the next cropping season need to be very accurate. Also, irrigation is extremely promising and should be promoted for small hillside farming. Our methodology is useful for the ex-ante cost-benefit assessment of adaptation instruments for specific farms. We then organized the first Adaptation to climate change in Guanacaste contest to integrate promising innovations that were being implemented in the region in the bio-economic model. 12 ideas were received, and 3 selected for receiving a prize from the hand of the President of the Republic of Costa Rica. The first prize went to Asociacion Organicos el Cerro,

a group of 22 farmers located in a tiny rural community in the mountains north-west of Nicoya, who uses small on-farm reservoir for year round organic production, but face many constraints that threaten the sustainability of the farms. We helped them build a strategic business plan with a multi-value chain approach. The formulation of the mission, vision and strategic objectives was participatory and iterative, and we developed a visualization of the value chain as well as a bio-economic model to identify and value opportunities for improvement and growth. We found that the agro-hydrologic farming system "Orgánicos el Cerro" is strong because it is diversified, which allows for flexibility in cropping choices in relation to evolving constraints and shocks. Investments in transport and collections centers were found to be more promising than building more water reservoirs, and by a large margin. The farming system and multi value chain modelling approach, which now include a Markov chain rainfall simulator, is an innovative way to understand and improve productive systems by integrating the regional context.

Guanacaste farmers were also surveyed regarding their reasons for participation (or non-participation) in PES program (Payment for Ecosystem Services), their preferences for PES, and overall environmental values, to better understand their motivation towards PES and provide insight for incentive program design. Results indicate strong environmental concern and support for all types of incentives (i.e. both monetary and non-monetary) across both participants and non-participants. Farmers reported they would engage in more environmentally oriented activities with adequate incentives. Program design recommendations to address existing farmers' concerns with equity (who gets to participate) and autonomy (who decides how the programs are run) include encouraging agency at the local level, reducing focus on additionality at the farm level, and reducing the burden of monitoring. We found that understanding existing attitudes and values and adapting PES accordingly may encourage participation and satisfaction with such programs.

Research also addressed perceptions of actors that do not live in the region. We explored tourist interest in financially supporting conservation in Guanacaste, and found that they identify strongly with the concepts that underpin ecotourism, and their desire to contribute financially being most tied to local NGOs. This suggests an overall appreciation for nature and environmental stewardship by tourists, and it was therefore surprising there was limited knowledge of the drought that was hitting hard the region at the time of the interviews. Similarly, willingness to pay for conservation was not influenced by awareness of drought, but by factors that point to a connection to place, suggesting that financial support from tourists may be leveraged by pointing to and enhancing such connections.

Finally, we focused on how birds are responding to climate-change induced drying and habitat conversion from forest to agriculture in Guanacaste, Costa Rica. After surveying entire bird communities in forests and farms, in both wet and dry areas, we detected 3813 individuals of birds from 126 different species. We analyzed diversity across the regional scale and found that different bird species are found in wet areas as compared to dry areas and in forests as compared to agriculture. Our analyses showed that land-use (forest vs. agriculture) explained more variation in bird community changes than precipitation. Similar species were found across the

regions, in both wet and dry areas. We found a strong relationship between how a species responds to habitat conversion and how it responds to climate drying.

Governance, co-design and stakeholders' engagement (CIRAD, CATIE)

To help positioning our action research in the context of drought, we sought to better understand the relationship between institutional actors associated with water resources during a conflict. We analyzed 5 cases in the region of Guanacaste in which there was a conflict related to water resources: in the DRAT, in the Potrero – Caimital watersheds, in the communities of Mala Noche, Costa, and Sardinal. We interviewed actors involved in the generation and resolution of the conflict, and analyzed their participation in relevant areas for decision-making associated with water shortage. Most conflicts were related to nonconformity and competition about water resources in tourist areas, between neighboring communities, and between the domestic, agricultural and livestock sectors. Local organizations were largely present when the conflict developed (59.4%), while for conflict resolution organizations at national and local scales were the most relevant (45.3%); actors from the regional scale were less involved in both stages of the conflict. Water service providers were most involved in the stages of conflict generation, often in relation to disputes over concessions to private entities, as well as over water use and quality. We then developed, together with stakeholders, processes and tools to help achieving drinking water security through community organization in the region.

We started with a participatory process in two contrasting communities, Colas de Gallo and Cuajiniquil near Nicoya, Guanacaste, Costa Rica, which suffered drinking water shortages during the drought event in 2015. Representatives of local organizations showed interest in developing a capacity building process for administering and managing rural aqueducts. We conducted 16 meetings in both communities, including several participatory modelling sessions with an adaptation of the Wat-A-Game toolkit for rural aqueducts, visits for exchanging experiences between both communities and other community-based organizations, and learning sessions. The WAG-ASADAS game proved to be a powerful trigger for community engagement, by helping participants grasp the rural aqueduct socio-hydrological system and imagine solutions to on-going problems. Field exchanges and talks by local leaders further enhanced trust and engagement. As a result, Colas de Gallo individuals got organized for improving their rural aqueducts, collecting a small fee from houses and organizing funding events. An unexpected process of collaboration emerged between both communities, where the most endowed community of Cuajiniquil committed to support Colas de Gallo in their local development endeavors. We also contributed to the establishment of links between individuals, organizations, and public institutions supporting community development in the region, enhancing community opportunities for accessing the external resources required for improving the rural aqueduct infrastructure and local organization.

In parallel a Values-driven, agent-based hybrid simulator was then developed for seeking consensus among water stakeholders from different sectors and scales. This was done by unfolding a participatory process for improving resilience to drought and reducing water

disputes in the Potrero-Caimital watershed, a few km west of the city of Nicoya. The process involved co-designing ContaMiCuenca (Spanish for 'Tell My Watershed'), an interactive, agent-based simulator of the actual environmental dynamics of that specific watershed. The hybrid simulation runs involve both players' decisions and automated calculations generated by the underlying agent-based model. We collectively assessed the water issues in the watershed, defined the objectives of the process, and developed several versions of ContaMiCuenca for environmental education and decision-making with adults and children. Simulation sessions with adults resulted in discussions regarding the need to improve the model accuracy, and to make it relevant for decision-making. This helped us to identify knowledge gaps in the groundwater pollution and aquifer dynamics, which were addressed to improve collective learning. Children emphasized the need for coordination and awareness raising, which contrasted with adult perspectives. Difficulties arose, however, in the decision-making phase and the formalization of collective rules. These arose primarily from existing tensions around water among stakeholders, which the model co-construction and participatory simulations had failed to fully resolve. To encourage participants to engage in a constructive debate with a positive attitude to arrive at win-win solutions, we (a) framed the ContaMicuenca interactive simulations within a value-based consensus game, and (b) conducted between round self-evaluations and debriefing. This proved to be a powerful way of generating a constructive atmosphere of trust and cooperation, in which positive emotions shaped the nature of the debates and impelled stakeholders to reach agreements based on overarching aspirations and responsible behaviors, and rooted in principles of sustainability for the greater good. Our findings provide insight and guidance for improving trans-generational engagement of water stakeholders in the development of sustainable communities in a context of water scarcity, limited technical information, weak water governance and climate change. During this process the agent-based modeling platform CORMAS was considerably improved to enable the hybrid modelling that has proven to be effective for collective learning (see section E.3).

C.5 EXPLOITATION OF RESULTS

Our approach for impact was premised on three understandings. First, what scientists find as useful information may be different from what users recognize as relevant information for decision-making (Lemos et al., 2012). Second, the heterogeneity of users' knowledge and frames of references presents a challenge for finding a common reference point, which can be partly addressed through decision support tools (or "boundary objects/artifacts") (Queste et al., 2011). Third, cognitive researcher shows that the processes people use to access information (either analytically or experientially) affects how that information is used, therefore thus making the way in which stakeholders engage with tools critical (Leclerc et al, 2011).

Impact, Engagement and dissemination

FuturAgua's three main objectives for impact, engagement and dissemination: (i) help overcome key information gaps (e.g., climate forecasts, aquifer monitoring and models), (ii) help identify

and structure key regional decision contexts to shape water security, and (ii) provide a basis for user ownership, understanding, and ongoing involvement with the research findings. Part of those objectives were attained through participatory research described in the previous section. In addition, FuturAgua had also a strong local communication and dissemination component, which involved the stakeholder's advisory group and the Municipality of Nicoya. Finally three projects have emerged which benefitted from FuturAgua research (section E.3).

FuturAgua dissemination was primarily oriented to Spanish-speaking audience of the region. It included preparing a dissemination plan, mapping of the media, involving the Press, organizing and participating in local events, web presence, local and regional mailing lists, Newsletters, Research Briefs, as well as tools in open access, organization of training events, and participation to local water and drought-related events. International audiences were reached in English, through conferences and journal articles. UBC obtained 30000CAN$ to complement FuturAgua dissemination and training in Canada (UBC) and Nicoya (UNA, Fundacion Nicoyagua).

Web presence

FuturAgua website (www.futuragua.ca) has received ~3700 visits per year (~15000 in 2014-2017), with 2-3 times increase in reach when new material was added such as Web notes or Research Briefs. FuturAgua was also featured on the Facebook page of CATIE's PBByCC's and GWP Costa Rica's Facebook pages.

Newsletters, Research Briefs, and Videos

We produced 3 newsletters aiming a the local stakeholders, the first to present the project, the second to inform about research advances at mid-term, and the third to present major research results. They have been printed in 1000-2000 copies, which were distributed during events and visits, and put online on Futuragua's website. The Research briefs were meant for delivering quickly FuturAgua research to a technical Spanish speaking public. To date eight have been put on FuturAgua website, sent to a local mailing list of 47 key people related to water management, to a regional mailing list of 1349 people, and to the Global Water Partnership who distributed it 407 people and 203 member organizations through its electronic newsletter. The Research briefs have also been submitted to Orton Commemorative Library open access repository of CATIE (http://bibliotecaorton.catie.ac.cr/). Four new research briefs will be completed and disseminated during the first semester of 2018.

We produced 3 short videos (to be uploaded on www.vimeo.com/futuragua), about (i) the ContaMiCuenca process with schoolchildren and stakeholders of Potrero-Caimlital watersheds, (ii) the WAG-Asadas process for community drinking water, and (iii) the FuturAgua project as a whole.

Press and TV

We produced 5 press releases and 4 news articles, and worked closely with newspapers *Semanario Universitario* (10000 issues weekly, 650/day Facebook views), one of the most respected in the country and a column on climate Change (Ojo al Clima), and *La Voz de Guanacaste*, an influential bilingual regional print and online media that produces investigative and data journalism, with 193 distribution points and a website with 170 views/day. The first prizes of the FuturAgua adaptation to drought contest were provided by the President of the Republic of Costa Rica during the Day of Annexion of Nicoya, an historic event that has national news coverage every 25th of July. Futuragua final event was covered by *Primero en Noticia* and *Bajura Channel*, a new cable TV that covers Guanacaste news.

Training, manuals and tools

We organized one training session on agent-based modelling at UCR in San José, and two on bio-economic modelling at the National University – UNA in Nicoya. The Connection Grant allowed to organize a full day of demonstration by several researchers from UBC, CIRAD, and UNA, and to prepare a manual synthetizing FuturAgua approach, results, and lessons learnt. Most instruments and tools are now in the hand of Fundacion Nicoyagua or UNA: Arduino monitoring stations, the WAG-Asadas Cards game, the ContaMicuenca interactive simulator and the physical aquifer model. The Eddy Covariance towers remain at the sites as part of the new UBC project AgWIT with UNA. The latest version of ContaMiCuenca and of CORMAS are available at http://cormas.cirad.fr. The UBC data will be provided to local stakeholders once copyright issues are solved.

Engagement of local stakeholders

The Municipality of Nicoya has put in place several thematic interinstitutional coordination committees at regional level (CCCI for *Consejo Cantonal de coordinación Interinstitucional*). FuturAgua has worked closely with the Environment CCCI (which includes Futuragua partners NicoyAgua and UNA), in particular for developing the ContaMicuenca interactive simulator, and this collaboration will continue. Through the CCCI we expect to achieve agreements among stakeholders from the Potrero-Caimital watershed, as well as from local water committees and from schools, which will lead to improved freshwater security in the region. The main academic local partner of FuturAgua, the UNA (Nicoya and Liberia campuses), is firmly committed to local and regional development and water security, through HIDROCEC and CEMEDE research units. CATIE will pursue its commitment on raising awareness about climate change and water security in the region through its *ChorotAgua* project. In addition to UBC's AgWIT project, CATIE and CIRAD will seek funding for new projects that build on Futuragua's achievements. During Futuragua closing event, local stakeholders identified research gaps that we committed to address in future projects led by a balanced consortium of research and civil society organisations.

International reach

FuturAgua scientists attended 11 international conferences, as well as the Belmont forum events held in San Francisco in 2014 and 2016. FuturAgua contributed to a summary of the Belmont 2016 workshop, who focused on science communication and on co-design: participants provided a brief overview their coastal and Fresh water security projects, identified common themes and framed recommendations for future Belmont Forum projects (https://goo.gl/To3anh). Futuragua experience have been shared through a research consortium on participatory modelling (https://participatorymodeling.org) involving FuturAgua scientists; the group prepared a proposal for the Belmont Forum T2S call, which unfortunately was not selected, but there is a strong commitment for developing other collaborative projects. This group also chaired a session on participatory modelling at the Resilience conference in Stockholm in August 2017 where FuturAgua was featured (Gray et al, 2017).

The WAG-Asadas game was presented at COP22 in Tunis, as part of an initiative to build a community of practice around games evolving from the Wat-A-Game (WAG) concept. Futuragua's former project manager, now professor at UNA, is now the WAG focal point for Latin America.

Cormas, an open source modeling platform benefited from the work carried out on the ContaMiCuenca model, in particular on the human-machine interface for hybrid simulations. Hydrology modules have also been implemented. These new features are now available to the Cormas user community (320 researchers worldwide). At the same time, Futuragua made it possible to migrate the platform from the proprietary Smalltalk engine VisualWorks to Open-source Pharo. This on-going project targets users with no programming experience, and involves an international community of developers, which facilitates a wide dissemination of Cormas.

C.6 DISCUSSION

"FuturAgua" was the project's name coined by the stakeholders, as a word that means water for the future. Our work was to provide research findings useful in the region and beyond, and the key to the success of this project was the involvement of the stakeholders, from the very beginning. The project Stakeholders Advisory Group was a critical element of success, but its impact could have been enhanced with better integration in the leadership of the project.
Did we contribute to improving resilience to drought in Guanacaste, as promised? Despite large delays linked to difficulties in obtaining data and developing tools, we succeeded to provide most of what was planned and expected from the stakeholders, especially the long awaited water balance for the Potrero-Caimital watershed, as well as decision-making tools and alternatives, but this implied a great deal of adaptability from them and from the researchers, and a no-cost extension of one year for all research partners. The team simply worked around obstacles and disappointments to engage in a continuous learning process with the stakeholders, ensure a presence in the field and timely communication. Project wise, there were different expectations

from students, researchers and stakeholders. For some, the priority was to provide sound scientific evidence (and could not really share it until published), while others wanted policy incidence as soon as possible (with some opportunistic bias). Differences in views were also related to a misunderstanding of the role the researcher, about science in the making and "science faite" (Latour, 2001). This is an issue that should be addressed in future research projects like FuturAgua.

Despite the efforts invested in communication within the research consortium, some differences in research culture persisted, which, adding to the large delays in obtaining results, undermined the possibility of transdisciplinary research. Also, since most of the research was carried out by graduate students, we had to adapt to their timeframe and institutional rules, which eventually resulted in less data, methods and results sharing until the very end of the project, with little possibility left for integration and policy incidence. With the stakeholders playing an important part in steering the participatory modelling work asked for a lot of adaptability and adjusting expectations from both sides, which slowed the process and delayed the production of scientific papers.

C.7 CONCLUSIONS

With a complex design and a large research team from 4 countries, FuturAgua was challenging to unfold. The scientists did not manage to work together as much as was foreseen, but we did make a difference about water security in the region, with new scientific evidences and easy to use tools, through joint learning and a strong commitment with stakeholders. We laid the foundations for new projects, some which have emerged during the course of FuturAgua, and others that will be developed in a way that enables the kind of disciplinary integration that we are all dreaming of. We believe that such lessons are critical in realizing participatory modelling's potential to facilitate communities taking charge of their own future by using meaningful, appropriate, and illuminating modeling tools in local processes.

Was FuturAgua successful? From the stakeholders perspective it seems that it was:

- "*Yes it was successful, the results help us to make things better, the recommendations of the scientists are a great challenge for me to implement! We hope to use all results in different levels (monitoring, internal work, regulatory plans in the Municipality) and promote new research. However, we were expecting more interdisciplinary work.*" - Xinia Campos, ACT and NicoyAgua Fundation.
- "*We are satisfied and grateful to the whole team, for sharing their data and all of the results of the studies, but above all for knowing that we can apply these results as a municipality in the Regulatory Plan of Nicoya, parallel to a policy meeting the objectives and guidelines issued by the local government*" - Elizabeth Fernández, Municipalidad de Nicoya.
- "*Important information about the aquifer and its recharge was obtained. At the end of FuturAgua I hope we can continue with permanent monitoring of the quantity and quality of the water of the aquifer*". - Álvar Campos de Lemos, livestock farmer, former president of Curime ASADAS.

- "*I hope to obtain a copy of the water balance in order to contribute to the development of the towns and to reinforce the provisions of the Urban Planning Law. I am proud to have contributed a grain of sand for the success of the project.*" - Max Gómez Martínez, AyA.
- "*I expected that together we would take on together many high-value technical studies for the region. I thought there would be more interaction with us, the technicians of the local institutions. If we could do the project again, it would have a local board of directors with the participation of all relevant stakeholders.*" - Emel Rodríguez, ACT, Communal Water League.
- "*At first we were skeptical about the WAG-Asadas game, but in fact the process helped us understand the problems and foresee solutions, and it motivated our community to get organized. Now every household is contributing 500 colones [1$] monthly to manage our aqueduct, we formed a local development committee, and we are in the process of becoming an official ASADA.*"-Kathia Gonzales, Colas de Gallo.

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D LIST OF DELIVERABLES

No deliverables were included in the Project contract, however we committed to a series of list of milestones (MS) that guided its development.

MS No.	Designation	Nature*	Date of supply			Partners (underline the responsible partner)
			Initially planned	Re-scheduled	Deliv-ered	
1	Precipitation and temperature sequence from 1921 to present at daily resolution (A1a)	Data	7/14	--	Yes	UBC
2	Rainfall frequency distributions (A1b)	Data	7/14	--	Yes	UBC
3	Region wide hydrological modelling scenarios (A1c)	Data	11/14	11/15	Yes	UBC
4	Deploy water level monitoring stations (A2a, b)	Equipment	3/14	--	Yes	UBC
5	Semi-structured interviews (A3a)	Models	11/14	11/15	Yes	CMU
6	Report on predicted behaviours and value of information complete (A3b, c)	Report	5/15	5/16	Yes	CMU
7	Report on governance gaps, mismatches and capacity building needs (A4a, b)	Report	11/14	11/17	Yes	CATIE
8	Install Eddy covariance systems (A5a)	Equipment	03/14	--	Yes	UBC
9	Report on agricultural management practices in future conditions (A5b)	Report	01/16	4/17	Yes	UBC
10	Workshop 1: Priority Ecosystem (ES) Services, identification, drivers of ES change (A6a, b)	Report	11/15	9/15	Yes	UBC
11	Workshop 2: Institutional capacity to cope with change; identification of possible actions to mitigate or adapt to change (A6c)	Data	11/15	11/17	Yes	UBC
12	Experts on regional climate elicitation protocol (B1a)	Data	11/14	11/15	Yes	CMU
13	Catalogue of extreme weather events (B1b)	Data	3/15	--	Yes	CATIE
14	Complete future outcomes based on interviews and elicitations (B1c)	Data	7/15	1/16	Yes	CATIE/UBC
15	Evaluate coupled water supply/water demand scenarios on water security (B2a)	Model	11/16	7/17	Yes	UBC
16	Report on resiliency opportunities and barriers (B3a)	Report	7/16	--	No	CMU
17	Recommendations for design and layout (B3b)	Report	7/16	--	No	CMU
18	Stakeholder groups consultations (C1a, b, c)	Workshops	9/16	11/17	Yes	CATIE/CIRAD/UBC
19	Decision support tools (C2a)	Tools	7/16	9/17	Yes	CIRAD/CATIE
20	Project charter (D1a)	Report	1/14	--	Yes	UBC/CIRAD
21	Consortium Agreement (D1b)	Report	1/14	--	Yes	CIRAD/CATIE/UBC/CMU
22	FuturAgua Website (D1c)	Web site	5/14	--	Yes	CATIE/UBC/CIRAD
23	Monitoring & Evaluation Framework (D2a)	Framework	5/14	--	Yes	UBC
24	Project reports (D2b, c)	Reports	5/15	2/18	Yes	CATIE/CIRAD/UBC
25	Dissemination via Belmont meetings, external networks, home institutions, stakeholders, as described in impact plan (D3 a, b)	Several	2/13	2/18	Yes	CIRAD/CATIE/UBC/CMU

E PROJECT IMPACT

E.1 IMPACT ASSESSMENT INDICATORS

Number of publications and communications (to be detailed in E.2)

		Multi-partner publications	Single-partner publications
International	**Peer-reviewed journals**		10
	Books or chapters in books	6	5
	Communications (conferences)	7	11
France	**Peer-reviewed journals**		
	Books or chapters in books		4
	Communications (conferences)		
Outreach initiatives	**Popularization articles**	3	9
	Popularization conferences		3
	Others	10	3

Other scientific valorization factors (to be detailed in E.3)

	Number, years and comments (Actual or likely valorizations)
International patents obtained	
International patents pending	
National patents obtained	
National patents pending	
Operating licences (obtained / transferred)	
Company creations or spin-offs	
New collaborative projects	CATIE: Chorotagua Project (100 k€, 2015-2018; Costa Rica Adaptation Fund): An opportunity to showcase Futuragua's results for a diverse audience from civil society. UBC, UNA: Agricultural Water Innovations in the Tropics (AgWIT) partnership (1.5M€, 2017-2020; Water JPI 2016 and ERA-NET. AgWIT is testing and assessing water management strategies and decision pathways for resilience of crops under current and future climatic conditions. UBC, CIRAD: UBC Connection grant (25k€): This project helped complement the dissemination of FururAgua results through a manual and two training events.
Scientific symposiums	Jornada de transferencia de conocimiento, Proyecto FuturAgua, UNA-Chorotega, Nicoya, 3 de noviembre, 2017.
Others (specify)	**New partnerships** National University of Costa Rica (UNA): HIDROSEC and CEMEDE research units. Integration of a research consortium on participatory modelling (https://participatorymodeling.org). **Open access platforms and their networks** The WAG-Asadas game was presented at COP22 in Tunis, as part of an initiative to build a community of practice around games evolving from the Wat-A-Game (WAG) concept. Futuragua's former project manager, now professor at UNA, is now the WAG focal point for Latin America. Cormas, an open source modeling platform benefited from the work carried out on the ContaMiCuenca model, in particular on the human-machine

	interface for hybrid simulations. Futuragua made it possible to migrate the platform from the proprietary Smalltalk engine VisualWorks to Open-source Pharo, which involves an international community of developers. **Open access prototypes and tools** The project developed open access interactive simulator ContaMiCuenca and the WAG-Asadas card game (CC-NS-SA). The Arduino sensors developed for water monitoring are now being maintained by students of UNA.

E.2 LIST OF PUBLICATIONS AND COMMUNICATIONS

Peer review journals

title	year	authors	journal	institutions	International/ France
Sustainability assessment of water governance alternatives: the case of Guanacaste Costa Rica.	2016	Kuzdas C., Warner, B., Wiek, A., Vignola,R., Yglesias, M., Childers D.L.	Sustain Sci (2016) 11:231–247	CATIE	International
Relational values resonate broadly and differently than intrinsic or instrumental values, or the New Ecological Paradigm	2017	Klain, S. C., Olmsted, P., Chan, K. M., Satterfield, T	PLOS1, https://doi.org/10.1371/journal.pone.0183962	UBC	International
Agriculture erases climate-driven β-diversity in Neotropical bird communities	2018	Karp, D., Frishkoff, L.O., Echeverri Ochoa, A., Zook, J., Juárez, P. J., Chan, K. M.	Glob Chang Biol. 24(1):338-349. doi: 10.1111/gcb.13821. Epub 2017 Aug 18.	UBC	International
Bimodal seasonal rainfall model for evaluating longterm climate model projections	2017	Almutairi, B., Grossmann, I., Small, M.	International Journal of Climatology (in review).	CMU	International
Identifying the potential of governance regimes to aggravate or mitigate local water conflicts in regions threatened by climate change.	2015	Kuzdas, C., Warner, B., Wiek, A., Yglesias, M., Vignola, R., & Ramírez-Cover, A. (2015).	*Local Environment*, 1-22. doi:10.1080/13549839.2015.1129604	CATIE	International
Developing a Hydrologic Monitoring Network in Data-Scarce Regions Using Open-Source Arduino Dataloggers.	2016	Hund, S. V., Johnson, M. S., & Keddie, T.	*Agricultural & Environmental Letters, 1*(1). doi:10.2134/ael2016.02.0011	UBC	International
Stakeholder perceptions of water systems and hydro-climate information in Guanacaste, Costa Rica.	2016	Babcock, M., Wong-Parodi, G., Small, M. J., & Grossmann, I.	*Earth Perspectives, 3*(1), 1-13. doi:10.1186/s40322-016-0035-x	CMU	International

Climate change and habitat conversion favour the same species.	2016	Frishkoff, L. O., Karp, D. S., Flanders, J. R., Zook, J., Hadly, E. A., Daily, G. C., & M'Gonigle, L. K.	*Ecology Letters, 19*(9), 1081-1090. doi:10.1111/ele.12645	UBC	International
Hybrid governance for drought risk management: the case of the 2014 El Niño in Costa Rica.	2018	Vignola R, Kuzdas C, Poveda K, Bolaños I.	International Journal of Disaster Risk Reduction (submitted)	CATIE	International
Information-sharing actors across scales and sectors for managing drought risk in water conflict-prone areas: a policy network analysis approach.	2018	Vignola R, Kuzdas C, Poveda K, Pacheco A, Bolaños I, Rivera P.	Journal of Water and Climate Change (submitted)	CATIE	International

Books or book chapters

title	Year	authors	publication	institutions
Adaptation a la variabilité climatique: Evaluation de différents outils d'adaptation du secteur agricole au Guanacaste, Costa Rica.	2014	Larghi, M.	M. Sc. Thesis Ecole Nationale Superieure D' Agronomie Et Des Iindustries Alimentaires. (https://goo.gl/XgiV5j)	CIRAD
Adaptación a la variabilidad Climática: evaluación de diferentes medidas de adaptación en el sector agrícola de Guanacaste, Costa Rica	2014	Larghi, M.	M. Sc. Thesis Ecole Nationale Superieure D' Agronomie Et Des Iindustries Alimentaires. (Spanish translation https://goo.gl/LZ5rSZ)	CIRAD
Exploring and Bridging Group Divides in Climate Communications	2017	Babcock, M.	Ph.D. thesis, Carnegie Mellon University, (https://goo.gl/J6XhfD)	CMU
For love or money: Harnessing environmental values and financial incentives to promote conservation stewardship	2017	Olmsted, P.	Ph.D. thesis, University of British Columbia, (https://goo.gl/VCKQhS)	UBC
Strategic planning for sustainable organic hillside agriculture with a farm system and value chain model in Nicoya, Guanacaste	2017	Jeroen Houdijk	M. Sc ; thesis, CATIE (https://goo.gl/2nuw5s)	CIRAD/CATIE
Renforcement des conditions d'une résilience du développement social et économique face à la sécheresse par l'amélioration d'outils décisionnels Guanacaste, Costa Rica	2017	Melissa Gillet	Lic. Pro thesis, Institut Universitaire et Technologique de Caen.	CIRAD
Comprendre et accompagner les dynamiques d'utilisation des ressources en eau: Mise en place d'une démarche de Modélisation d'Accompagnement dans le Guanacaste, Costa Rica	2016	Camille Belmin	Rapport de stage de césure, Agroparistech.	CIRAD
Companion modelling for involving water stakeholders in educational awareness and decision-making.	2018	Leclerc G, Bommel P, Belmín C, Gillet M, Bautista P	Romero J (ed): The FuturAgua project: An interdisciplinary study of Climate Adaptation in Guanacaste,Costa Rica. Summary of research findings.	CIRAD/CATIE

Achieving drinking water security through community organization in Guanacaste, Costa Rica.	2018	Leclerc G, Bautista P, Bommel P	Romero J (ed): The FuturAgua project: An interdisciplinary study of Climate Adaptation in Guanacaste,Costa Rica. Summary of research findings.	CIRAD/CATIE
Farming system strategic planning with a multi value-chain approach.	2018	Houdijk J, Barbier B, Rodriguez R, García R, Leclerc G	Romero J (ed): The FuturAgua project: An interdisciplinary study of Climate Adaptation in Guanacaste,Costa Rica. Summary of research findings.	CIRAD
Evaluation of different adaptation tools for agriculture in Guanacaste.	2018	Larghi M, Leclerc G, Barbier B		CIRAD
Modelacion de acompañamiento para involucrar a los actores del agua en la concientización educativa y la toma de decisiones.	2018	Leclerc G, Bommel P, Belmín C, Gillet M, Bautista P	Romero J (Ed): El proyecto futurAgua: Estudio interdisciplinario sobre la adaptación al clima en Guanacaste, Costa Rica. Resumen de resultados de investigacion.	CIRAD/CATIE
Alcanzando la seguridad del agua potable a través de la organización comunitaria en Guanacaste, Costa Rica.	2018	Leclerc G, Bautista P, Bommel P	Romero J (Ed): El proyecto futurAgua: Estudio interdisciplinario sobre la adaptación al clima en Guanacaste, Costa Rica. Resumen de resultados de investigacion.	CIRAD/CATIE
Planificación estratégica del sistema agrícola con un enfoque de múltiple cadena de valor.	2018	Houdijk J, Barbier B, Rodriguez R, García R, Leclerc G	Romero J (Ed): El proyecto futurAgua: Estudio interdisciplinario sobre la adaptación al clima en Guanacaste, Costa Rica. Resumen de resultados de investigacion.	CIRAD/CATIE
Evaluación de diferentes instrumentos de adaptación del sector agrícola en Guanacaste.	2018	Larghi M, Leclerc G, Barbier B	Romero J (Ed): El proyecto futurAgua: Estudio interdisciplinario sobre la adaptación al clima en Guanacaste, Costa Rica. Resumen de resultados de investigacion.	CIRAD
Temporal and Spatial Variability of Annual Rainfall Patterns in Guanacaste, Costa Rica	2016	Steyn D, Moisseeva, N, Harari, O, Welch W.	UBC open collections (https://goo.gl/SrjiSy)	UBC

Pharo Smalltalk Code Generation from UML model	2017	Uhnak P	https://github.com/dynacase/class-editor/blob/master/docs/code-generation/uml-to-code.md	CIRAD
PIM to PSM transformation specific to CORMAS context and targetting Visual Works.	2017	Uhnak P	https://github.com/OpenPonk/class-editor/blob/master/docs/vw-code-generation/pim-psm.md	CIRAD
Cormas Pharo Port	2018	Morales H.	https://github.com/cormas/cormas/wiki/Pharo-Port	CIRAD
The FuturAgua project: Summary of an interdisciplinary research findings in Guanacaste, Costa Rica	2018	Romero J (ed)	(in press)	UBC, CIRAD, CMU, CATIE
Resumen de resultados de investigaciones interdisciplinarias en Guanacaste, Costa Rica	2018	Romero J (ed)	(in press)	UBC, CIRAD, CMU, CATIE
Climate, water use and their impacts on the inter-connected resource of surface and groundwater	2018	Hund S.	Ph. D. thesis, University of British Columbia (to be completed in 2018).	UBC

Communications (conferences)

title	year	authors	Institution	Conference
Companion modelling contribution for understanding and supporting water management decisions in the climate change context	2015	Bautista P, Bommel P, Belmin C.	CIRAD/CATIE	Fora: Adaptation strategies for climate change in agriculture, Heredia, Costa Rica.
Understand and support hydric resources management decisions under a context of climate change. A companion modelling approach for Nicoya, Guanacaste, Costa Rica.	2015	Belmin C, Bommel P, Bautista P, Leclerc G, Vignola R.	CIRAD/CATIE	II Congress of Agricultural Economics and Agribusiness, San Jose, Costa Rica
Achieving water security through community-based agreements in rural Northwestern Costa Rica.	2016	Bautista P, Bommel P, Campos X, Suarez A, Leclerc G.	CIRAD/CATIE	Paper presented at the AGU Fall Meeting 2016, San Francisco, US.
The necessary burden of involving stakeholders in agent-based modelling for education and decision-making.	2016	Bommel P, Bautista P, Leclerc G, Belmin C, Morataya R, Antona M.	CIRAD/CATIE	AGU Fall Meeting 2016, San Francisco, US
Challenges for involving water stakeholders in educational and decision-making participatory processes supported by ABM.	2016	Bautista P, Belmin C, Leclerc G, Antona M, Morataya R, Bommel P.	CIRAD/CATIE	Paper presented at the Environmental modelling and software for supporting a sustainable future. IEMSs 2016, Toulouse, France.
Ex-ante evaluation of agricultural adaptation tools for drought CSA 2015	2015	Larghi M, Leclerc G, Barbier B	CIRAD	CSA Global Science Conference 2015. Montpellier, France
Management of freshwater resources given stakeholders' perceptions	2014	Wong-Parodi G, Babcock M, Small M, Grossmann I.	CMU	AGU 2014. San Francisco, US
Enhancing adaptation and resilience to drought in dry tropical socio-ecological systems: The Guanacaste, Costa Rica example.	2014	McDaniels T, Babcock M, Chan K, Grossmann I, Hund S, Johnson M, Larghi M, Leclerc G, Olmsted P, Romero J, Small M, Steyn D, Vignola R, Wong-Parodi, G.	UBC, CMU, CATIE,CIRAD	AGU 2014. San Francisco, US

Eliciting climate experts' knowledge to address model uncertainties in regional climate projections: A case study of Guanacaste, Northwest Costa Rica (GC13F-0728).	2014	Grossmann I.	CMU	AGU 2014. San Francisco, US
Hydrologic monitoring using open-source Arduino logging platforms in a socio-hydrological system of the drought-prone tropics, Guanacaste, Costa Rica	2015	Hund S., Johnson M, Steyn D, Keddie T, Morillas L.	UBC	AGU, 2015, San Francisco
Agricultural water use, crop water footprints and irrigation strategies in the seasonally dry Guanacaste region in Costa Rica	2017	Morillas L, Johnson M, Hund S, Steyn D.	UBC	EGU 2017. Geophysical Research Abstracts Vol. 19, EGU2017-11851, 2017
Socio-Hydrological model to inform community adaptation to seasonal drought and climate variability in rural agricultural watersheds in Costa Rica	2017	Hund S, Johnson M, Morillas L, McDaniels T, Romero J, Allen D.	UBC	AGU 2017, New Orleans
Carbon and water fluxes and footprints in tropical agricultural systems under rainfed and irrigated conditions	2017	Johnson M, Lathuilliere M, Morillas L, Dalmagro H, D'Acunha B, Kim Y, Suárez A, Couto E.	UBC	AGU 2017, New Orleans
Freshwater security in agricultural watersheds of the wet-dry tropics, Guanacaste, Costa Rica	2016	Hund S, Johnson M, Morillas L., Allen D.	UBC	AGU 2016, Dec. 12-16, San Francisco
Integrating socio-hydrology with ecohydrology to evaluate freshwater security in relation to multiple, interacting stressors in a drought-prone tropical region	2016	Johnson M, Hund S, Morillas L., Steyn D.	UBC	Annual Meeting of the American Association of Geographers, San Francisco
Payments for Ecosystem Services and Adaptation in Costa Rica	2014	Olmsted P.	UBC	Institute for Resources, Environment and Sustainability Symposium. Vancouver BC, April 10, 2014
Cormas, an Agent-Based simulation platform for coupling human desicion with computerized dynamics,	2015	Bommel P, Becu N, Le Page C, Bousquet,F	CIRAD	46th ISAGA conference, Kyoto, Japan, 17-21/7/2015.

Playing with models. How to use agent-based models with stakeholders for understanding social-ecological systems.	2017	Bommel P, Bonnet M.P, Leclerc G, Coudel E, Le Page C.	CIRAD	Resilience 2017 : Resilience frontiers for global sustainability, 2017-08-20/2017-08-23, Stockholm (Suède). http://media.resilience2017.org/2017/08/Resilience-2017_Final-pdf-program.pdf
Strategic planning for sustainable organic hillside agriculture with a farming system and value chain model in Nicoya, Guanacaste.	2016	JHoudjik J, Leclerc G, Barbier B, Ramirez R, Garcia R.	CIRAD	Agri-Chains and Sustainable development. Montpellier, France 12-14 December 2016.
The futuragua project		McDaniels T, Leclerc G, Bommel P, Bautista P, Johnson M, Wong-Parodi G.	CIRAD, UBC, CMU, CATIE	Belmont Forum Synthesis Workshop, December 10-12, 2016, San Francisco, California
Facilitating the Design of ABM and the Code Generation to Promote Participatory Modelling.	2016	Uhnak P, Bommel P.	CIRAD	In: Sauvage, S.,Sánchez-Pérez, J.M., Rizzoli, A.E. (Eds.), 2016. Proceedings of the 8th International Congress on Environmental Modelling and Software, July 10-14, Toulouse, FRANCE. ISBN: 978-88-9035-745-9. pp. 827-835
Pragmatic Insights: Live UIs for Agent-Based Modelling in Pharo	2017	Grover J., Papoulias N., Stinckwich S. and Bommel P.	CIRAD	ESUG IWST 2017, International Workshop on Smalltalk Technologies, September 2017, Maribor, Slovenia. doi: 10.1145/3139903.3139915
Purpose, Processes, Partnerships, and Products: 4Ps to advance Participatory Socio-Environmental Modeling.	2017	Gray, S., Voinov, A., Bommel, P., Le Page, C., Scmitt-Olabisi L.	CIRAD	In: Resilience 2017. Stockholm Resilience Centre, Resilience Alliance. Stockholm. Abstract, p.28-29.

Outreach initiatives: popularization articles

title	year	authors	institutions	publication
FuturAgua Newsletter 1	2015	Poveda K, Leclerc G (Eds)	CIRAD,CATIE	www.futuragua.ca and print
FuturAgua Newsletter 2	2016	Bautista P, Leclerc G (Eds)	CIRAD,CATIE	www.futuragua.ca and print
FuturAgua Newsletter 3	2018	Arguello M, Leclerc G (Eds)	CIRAD,CATIE	www.futuragua.ca and print
Research Brief 1: Desarrollando una red de monitoreo hidrológico en zonas carentes de datos usando registradores de datos de código abierto de Arduino	2017	Hund S, Johnson M, Keddie T.	UBC	www.futuragua.ca
Research Brief 2: Percepción de los actores locales y el Uso de Pronósticos	2017	Babcock M, Wong-Parodi G, Small M, Grossman I	CMU	www.futuragua.ca
Research Brief 3 Variabilidad espacial y temporal de los patrones de lluvia anual en Guanacaste, Costa Rica	2017	Steyn D, Moiseeva N, Harari O, Welch W	UBC	www.futuragua.ca
Research Brief 4: Considerando valores y actitudes al desarrollar programas de incentivos en comunidades rurales y más allá	2017	Olmsted P, Honet-Rosés J, Satterfield T Chan K	UBC	www.futuragua.ca
Research Brief 5: Impacto sobre el agua por los turistas y nuevas formas de financiamiento para la conservación en Guanacaste	2017	Olmsted P, Honet-Rosés J, Satterfield T, Chan K	UBC	www.futuragua.ca
Research Brief 6: Cormas, una plataforma mutiagente para la modelización interactiva	2017	Bommel P, Becu N, LE Page C, Bousquet F, Leclerc G	CIRAD	www.futuragua.ca
Research Brief 7: Dinámicas de uso del agua en fincas agrícolas intensivas de la provincia de Guanacaste, Costa Rica	2017	Morillas L, Johnson M	UBC	www.futuragua.ca
Research Brief 8: La agricultura homogeniza la diversidad de aves generada por el gradiente de precipitación en Guanacaste, Costa Rica	2017	Karp D, Frishkoff L, Echeverri A, Zook J, Juárez P, Chan K.	UBC	www.futuragua.ca
Research Brief 9: Evaluación de diferentes instrumentos de adaptación del sector agrícola en Guanacaste	2018	Larghi M, Leclerc G, Barbier B	CIRAD	(in press)

Outreach initiatives: popularization conferences

title	year	authors	institutions	Conference/event
Un réseau de facilitateurs de l'adaptation socio-environnementale Pour renforcer les capacités des communautés Face aux changements climatiques et socio-économiques: Atelier de travail et réunion de lancement du réseau.	2016	Bautista P, Leclerc G, Bommel P.	CIRAD (UNA, IRSTEA)	COP22 parrallel event. 14-16 nov 2016.
Demostración del modelo físico de acuífero	2017	Bommel P, Leclerc G, Morataya R	CIRAD (UNA)	Festival Chorotagua, Nicoya, 29 October 2O17
Primer Concurso de adaptación a la sequía en Guanacaste	2016	Leclerc G, Bautista P, Campos X, Suarez A.	CIRAD (UNA, Nicoyagua, Nicoya municipality. Voz de Guanacaste).	Día de la anexión de Guanacaste, 25 July 2016.

Outreach initiatives: other

title	year	authors	institutions	Explanation
Modelos bio-económicos y cambio climático	2016	Barbier B, Leclerc G.	CIRAD	Group training Universidad Nacional de Costa Rica (UNA), 29/9/2016
Modelos bio-económicos y cambio climático	2017	Barbier B, Leclerc G.	CIRAD	Group training Universidad Nacional de Costa Rica (UNA), 19-21/04/2017
Modelización multi-agente para la gestión de recursos renovables	2017	Bommel P, Bonté B	CIRAD	Group training Universidad de Costa Rica (UCR), 6-10/03/2017
Spreading learning about social-ecological systems concerning water and climate change in the dry tropics of Central America.	2017	Morillas L, Bommel P, Leclerc G, Hund S, Johnson M, Steyn D	CIRAD, UBC	Group training at Una Nicoya 3/11/2017
Investigadores desarrollan método barato para saber cuánta agua le queda a Guanacaste	2016	Montes de Oca B	CIRAD, UBC (Voz de Guanacaste)	(https://goo.gl/pVmKBi)
Researchers develop an inexpensive method to measure how much water Guanacaste has left	2016	Montes de Oca B	CIRAD, UBC (Voz de Guanacaste)	(https://goo.gl/M9XLi8)
Guanacaste Has Highest Risk of Being Affected by Drought	2015	Bautista P	CIRAD/CATIE (Voz de Guanacaste)	(https://goo.gl/zC6r7g)
Guanacaste abre preguntas sobre su futuro en un planeta más caliente	2017	Arguedas Ortiz D	CIRAD (Semanario Universidad)	(https://goo.gl/FkETd3)
¿Qué está haciendo el Gobierno para dotar de agua a Guanacaste?	2015	Cruz MF	UBC, CIRAD, CATIE (El financiero Costa Rica)	(https://goo.gl/DBV1G1)
¿Cuáles fueron los proyectos ambientales que premió Luis Guillermo Solís el 25 de julio?	2016	Bautista P, Leclerc G.	CIRAD, CATIE (Voz de Guanacaste)	(https://goo.gl/bY1AQY)
Proyecto FuturAgua Comparte Resultados en Nicoya	2017	Arguello M	CIRAD/CATIE	Primero en noticias (https://goo.gl/evJQgr)
Ciencia busca mejorar el manejo del agua en Guanacaste	2017	Arguello M	CIRAD/CATIE	Press release
FuturAgua pone a la disposición los resultados de investigaciones en español	2017	Arguello M	CIRAD/CATIE	Press release
Proyecto FuturAgua comparte resultados y conocimientos con actores clave de Nicoya	2017	Arguello M	CIRAD/CATIE	Press release

Una visión económica más real de la finca es necesaria para decidir mejor	2017	Arguello M	CIRAD/CATIE	Press release
Una visión económica más real de la finca es necesaria para decidir mejor.	2017	Arguello M	CIRAD/CATIE	Web note
Preparando el modelo ContaMiCuenca	2017	Arguello M	CIRAD/CATIE	Web note
Niños y niñas de Curime ayudan a mejorar el modelo de ContaMiCuenca	2017	Arguello M	CIRAD/CATIE	Web note
FuturAgua pone a la disposición los resultados de investigaciones en español	2017	Arguello M	CIRAD/CATIE	Web note
El cambio climático y la deforestación se unen para homogenizar la biodiversidad	2017	Arguello M	CIRAD/CATIE	Web note
FuturAgua capacita, dialoga y transfiere conocimiento a estudiantes y agricultores	2017	Arguello M	CIRAD/CATIE	Web note
Proyecto FuturAgua comparte resultados y conocimientos con actores clave de Nicoya	2017	Arguello M	CIRAD/CATIE	Web note
ContaMiCuenca: un simulador interactivo para la gestión colectiva	2018	Morales R, Leclerc G, Bommel P.	CIRAD/CATIE	Video
WAG-Asadas: un juego serio para los acueductos rurales	2018	Morales R, Leclerc G, Bommel P.	CIRAD/CATIE	Video
El proyecto Futuragua: mejorar la resiliencia a al sequía en Guanacaste	2018	Morales R, Leclerc G, Bommel P.	CIRAD/CATIE	Video

E.3 LIST OF VALORIZATION FACTORS

New projects

CATIE: Chorotagua Project (100 k€, 2015-2018, Costa rica Adaptation Fund): "Implementado lo aprendido: fortaleciendo las capacidades de los pobladores de la Península de Nicoya para enfrentar los impactos del cambio climático en el recurso hídrico. This is an opportunity to showcase Futuragua's results for a diverse audience from civil society.

UBC, UNA: Agricultural Water Innovations in the Tropics (AgWIT) partnership (1.5M€, 2017-2020). Water JPI 2016 Joint Call for Transnational Collaborative Research Projects. ERA-NET Cofund WaterWorks2015. The project is testing strategies to lower agricultural impacts on water resources while improving the resiliency of tropical agricultural systems to climate change in several regions including Guanacaste. AgWIT will then assess water management decision pathways for rainfed and irrigated crops under current and future climatic conditions.

UBC, CIRAD: Connection grant (25k€): Spreading learning about social-ecological systems concerning water and climate change in the dry tropics of Central America. This project helped complement the dissemination of FururAgua results through a manual and two training events.

Scientific symposiums

UBC organized the "Jornada de transferencia de conocimiento, Proyecto FuturAgua", with UNA-Chorotega, Nicoya, November 3, 2017. Around 30 participants attended the 5 sessions: 1) Climatic drivers of drought in Guanacaste and ecohydrological consequences of drought; 2) Data collection of stream flow using low cost hydrological stations; 3) RPG session on ContaMiCuenca: an interactive simulator for the co-design of community rules for water security; 4) Participatory workshop: Water and agriculture in the Guanacastecan context; 5) Hydrological modeling (WEAP model).

New partnerships

Futuragua triggered the development of durable partnerships with the National University of Costa Rica (UNA), in particular its Liberia and UNA campuses and HIDROSEC and CEMEDE research units.
Futuragua experience have been shared through a research consortium on participatory modelling (https://participatorymodeling.org) involving FuturAgua scientists; the group prepared a proposal for the Belmont Forum T2S call, which unfortunately was not selected, but there is a strong commitment for developing other collaborative projects. This group also chaired a session on participatory modelling at the Resilience conference in Stockholm in August 2017 where FuturAgua was featured (Gray et al, 2017).

Open access platforms and their networks

The WAG-Asadas game was presented at COP22 in Tunis, as part of an initiative to build a community of practice around games evolving from the Wat-A-Game (WAG) concept. Futuragua's former project manager, now professor at UNA, is now the WAG focal point for Latin America.

Cormas, an open source modeling platform benefited from the work carried out on the ContaMiCuenca model, in particular on the human-machine interface for hybrid simulations. Hydrology modules have also been implemented. These new features are now available to the Cormas user community (320 researchers worldwide). At the same time, Futuragua made it possible to migrate the platform from the proprietary Smalltalk engine VisualWorks to Open-source Pharo. This on-going project targets users with no programming experience, and involves an international community of developers, which facilitates a wide dissemination of Cormas.

Open access prototypes and tools

The project developed open access interactive simulator ContaMiCuenca for the Potrero-Caimital watershed, which can easily ported to other areas or used as a capacity-building and awareness tool. The WAG-Asadas card game which has been produced in 20 copies under the Creative commons CC-NS-SA license, can also be downloaded or adapted. The Arduino sensors developed for water monitoring are now being maintained by students of UNA.

E.4 ASSESSMENT AND FOLLOW-UP OF PERSONNEL RECRUITED ON FIXED-TERM CONTRACTS (EXCLUDING INTERNS)

Identification				Before recruitment for the project			Recruitment for the project				After the project				
Surname and first name	Sex M/F	E-mail address	Date of last news	Last diploma obtained at time of recruitment	Place of studies (France, EU, outside EU)	Prior professional experience, including post-docs (years)	Partner who hired the person	Position in the project	Duration of missions (months)	End date of mission on project	Professional future	Type of employer	Type of employment	Relation with ANR project	Promotion of professional experience
Vignola Raffaele	M	Raffaele.vignola@wur.nl	02/2018	PhD	Outside EU	18	CATIE	PI	7	11/2017	Fixed-term	University	Researcher	N	O
Bautista Pavel	M	pavel.bautista.solis@una.cr	11/2017	PhD	Outside EU	14	CATIE	Research fellow/project manager	24	8/2016	Fixed-term	University	Researcher	Y	O
Kuzdas Christopher	M	Christopher.Kuzdas@gmail.com	11/2017	PhD	Outside EU	9	CATIE	Consultant	6	11/2017	Fixed-term	NGO	Researcher	N	O
Poveda Karina	F	koveda@earth.ac.cr	9/2017	BSc	Outside EU	1	CATIE	Consultant	6	8/2015	Fixed-term	University	Engineer	N	O
Silja Hund	F	siljahund@gmail.com	02/2018	MSc	EU	4	CIRAD	PhD Student	15	11/2017	Fixed-term	SME	Research	N	O